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Seasonal influence on vegetative growth and flower initiation of *Spathiphyllum*

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Vegetative growth and flower initiation of *Spathiphyllum* cultivars 'Alfa' and 'Cervin' were studied under various climatic conditions over a full year's growth cycle. The four production cycles started respectively on 18th March, 10th June, 10th September and 26th November 1998. These cycles are referred to as summer, autumn, winter and spring cultures respectively since the major part of the experimental period occurred in this specific season.

This study indicated that 'Alfa' and 'Cervin' reacted in different ways during the year. *Spathiphyllum* 'Alfa' initiated flowers independently of the attained vegetative biomass and flower initiation occurred when growth rate was slow or decreased considerably. In the winter and spring cycles, 'Alfa' was able to initiate flowers in an early vegetative stage (12.4 leaves and 7.4 leaves respectively), whereas the summer and autumn cultured plants were larger (29.5 leaves and 23.2 leaves respectively) at the start of flower initiation. For 'Alfa', the absence of temperatures above 26°C seemed to be an initial (essential) condition to start flower initiation. In addition to non-elevated temperatures, decreasing or low light intensities and shortening of the photoperiod were associated with the conversion from the vegetative to the generative stage. For *Spathiphyllum* 'Cervin', however, no linkage of climatic conditions and the start of generative development was observed. 'Cervin' required a more extensive vegetative development than 'Alfa' before flower initiation could take place. In any of the four culture cycles, flower initiation did not occur before the plants had formed approximately seven shoots and 24 leaves.

Introduction

Spathiphyllum is one of the main flowering pot plants in Europe and is generally sold with one or more inflorescences. Many Araceae, e.g. *Spathiphyllum* (Henny 1981), *Aglaonema* (Henny 1983), *Syngonium* (Henny *et al.* 1999) and *Dieffenbachia* (Henny 1980) can be stimulated to flower with a single application of gibberellic acid (GA). *Spathiphyllum* 'Mauna Loa', produced significantly more inflorescences per plant at the 1 000mg l^{-1} GA_3 treatment in comparison with 250mg l^{-1} GA_3 and 500mg l^{-1} GA_3 (Henny 1981). GA applications allow commercial production planning and regular marketing of flowering *Spathiphyllum* plants throughout the year. However, GA-treated plants often develop many, but smaller and distorted inflorescences and peduncles (Henny 1981, Vissers and Haleydt 1994). Moreover, GA-treated plants may also exhibit narrowing of new leaves and elongation of the petioles, resulting in a plant with unattractive foliage. Natural flowering *Spathiphyllum* on the other hand, have a high ornamental value because of their large, high quality inflorescences and attractive foliage. However, this non-chemical culture method results in longer and irregular production cycles, heterogeneous flowering and thus unpredictable marketing schedules.

Spathiphyllum is a tropical, day neutral, shade plant that flowers generally during spring, but rarely from August through December (Henny 1986). Thus, the required time for flowering can differ to a large extent depending on the growing season. Research by Hendriks and Scharf (1988), Hendriks (1992) and Verberkt (1993) demonstrated that elevated greenhouse temperatures (exceeding 26°C) during the summer months delayed flowering and prolonged the production period. Therefore it is possible that a particular, as yet unknown, combination of light and/or temperature triggers flower induction.

The final goal of this research was to control the flowering process of *Spathiphyllum* in a non-chemical way in response to the devaluation of the currently marketed GA-treated, plants. A preliminary study under standard greenhouse circumstances was carried out and focused on the influence of altering light and temperature conditions throughout the year on vegetative growth and flower initiation of *Spathiphyllum.*

Materials and Methods

Experimental design

Four production cycles started respectively on the 18th March, 10th June, 10th September and 26th November 1998. These cycles are respectively referred to as summer, autumn, winter and spring cultures since the major part of the growth period occurred in this specific season. Cultures ended respectively on the 13th January, 25th March, 21st June and 22nd June 1999. The experiment consisted of four treatments (growing seasons) with three replicates per treatment.

Plant material and growth conditions

Tissue cultured plants of *Spathiphyllum* 'Alfa' and 'Cervin' were potted in 13cm ebb and flood pots in a regular peat mixture. Temperature and ventilation set points were 20/21°C day and 22/23°C night respectively. No supplementary lighting was provided. Automated screens (65% shading) were closed above 350W m^{-2} global irradiation (registered outside) or 805µmol m^{-2} s^{-1} (calculation according to Beel and Volckaert 1992). CO_2 was provided light dependently (ranging from 500ppm to 600ppm CO_2 for a light intensity of 100W m^{-2} to 250W m^{-2} (outside)). Fertilisation with a standard nutrient solution was provided by an ebb and flood system. Irrigation was given according to normal commercial practice.

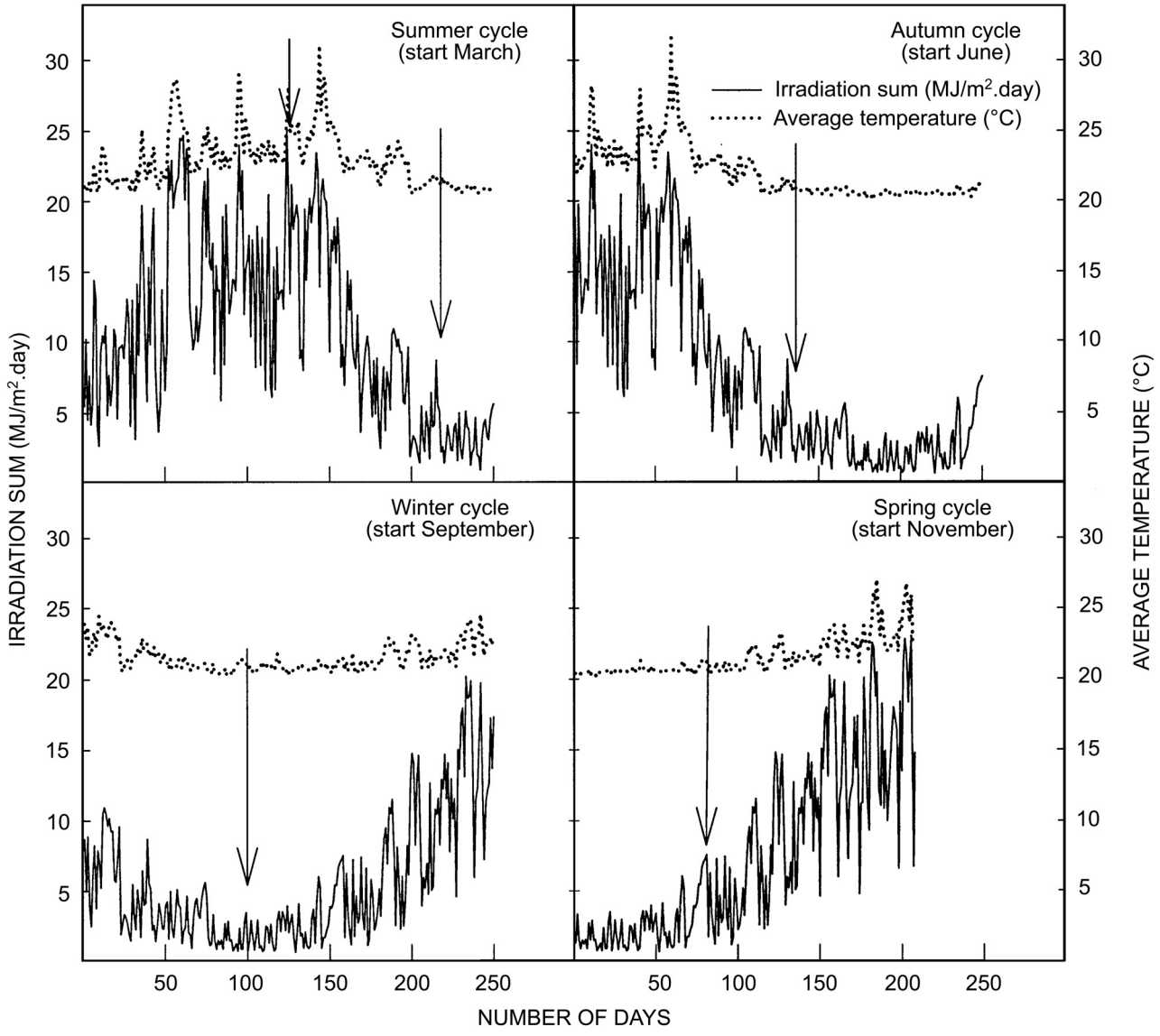

Figure 1: Daily irradiation sum (MJ m^{-2}) and average temperature (°C) during the four culture cycles, from March 1998 (start summer cycle) until June 1999 (end spring cycle). Arrow indicates the start of flower initiation of *Spathiphyllum* 'Alfa'

Climate

Irradiation was registered as global solar irradiation outside the greenhouse and temperature was registered inside the greenhouse. Figure 1 shows the irradiation sum (MJ m^{-2} day^{-1}) and the average temperature a day (°C) during the four culture cycles. Day zero corresponds to the potting date.

Plant measurements

Every two weeks, four plants per replicate (i.e. 12 plants per treatment) were randomly selected for destructive measurements. Total leaf area was determined with an image analysis system (Delta-T Devices, Cambridge, UK). Dry weight of leaf blades and petioles was measured after drying at 80°C for 24h.

The start and progression of flower initiation was determined by dissection of the main and secondary shoots (Figure 2). Flower initiation on a shoot results in the transition of its vegetative apex into an inflorescence meristem. After this transition the plant starts to develop new leaves from an axillary shoot that is developing near the flower apex.

The length of this new axillary shoot was classified in three categories (0–15mm, 15–50mm and more than 50mm). The evolution of the number of axillary shoots in each category (expressed as percentage of the total number of shoots per plant) allowed description of the generative development in every season. In this article the first detection of the lowest class of axillary shoots is referred to as the (approximated) start of flower initiation, whereas higher classes represent further floral development into full-grown flowers. The period between the start of the culture and the start of the flower initiation is described as 'pre-initiation period'.

Data analysis

Data were subjected to analysis of variance (SPSS data analyses). Differences among treatments were tested using Tukey's HSD-test at P = 0.05. A Gompertz function (three parameters) was fitted through leaf blade dry weight (Hunt 1982). Absolute growth rate (AGR) in mg per day was derived from this function.

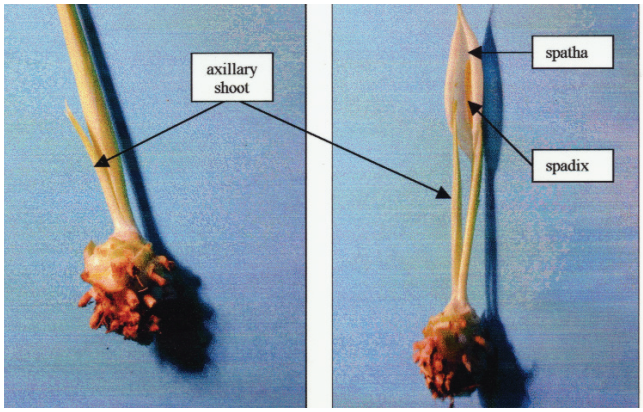

Figure 2: Macroscopic dissection method for flower initiation. Left: shoot has converted into the generative stage; the arrow shows the new vegetative, axillary shoot. Right: young flower inside the shoot

Results

Vegetative growth

Vegetative characteristics of *Spathiphyllum* 'Alfa' and 'Cervin' at the start of flower initiation showed significant differences for the four culture cycles (Table 1). As a result of the prolonged pre-initiation period in summer and autumn culture cycles, the 'Alfa' plants had a more extensive vegetative development at the start of flower initiation (29.5 leaves and 23.2 leaves respectively) compared to winter and spring cycles (12.4 leaves and 7.4 leaves respectively) (Table 1). In the spring cycle, 'Alfa' plants were able to initiate flowers at the single-shoot stage with approximately seven leaves. This indicates that 'Alfa' was able to initiate flowers at an early vegetative stage. For 'Cervin', however, a larger number of shoots and leaves were required prior to flower initiation. In the four culture cycles of 'Cervin', no flower initiation was observed until approximately seven shoots and 24 leaves were formed (Table 1). The seasonal differences of vegetative development at the start of flower

Table 1: Vegetative characteristics of *Spathiphyllum* 'Alfa' and 'Cervin' at the start of flower initiation (n = 12) for the four culture cycles

Culture cycle	Potting date	Start of flower initiation	Number of days	Number of leaves	Number of shoots	Leaf area (cm^2)	Total dry weight (g)
'Alfa'							
Summer	18 March	26 July[z]	131	29.5 a[y]	6.7 a	1 827 a	11.6 a
Autumn	10 June	18 Oct	131	23.2 b	5.6 b	1 621 b	10.5 b
Winter	10 Sept	15 Dec	97	12.4 c	3.3 c	517 c	3.3 c
Spring	26 Nov	22 Feb	88	7.4 d	1.1 d	258 d	1.2 d
'Cervin'							
Summer	18 March	13 July	117	43.0 a	11.6 a	2 057 a	13.9 a
Autumn	10 June	19 Oct	131	28.9 b	7.2 c	1 378 b	8.4 c
Winter	10 Sept	30 March	201	30.8 b	7.9 b,c	1 669 b	10.4 b
Spring	26 Nov	19 April	144	24.1 c	8.0 b	909 d	5.6 d

[z] early start of flower initiation
[y] mean separation for each cultivar in columns by Tukey's test, P = 0.05

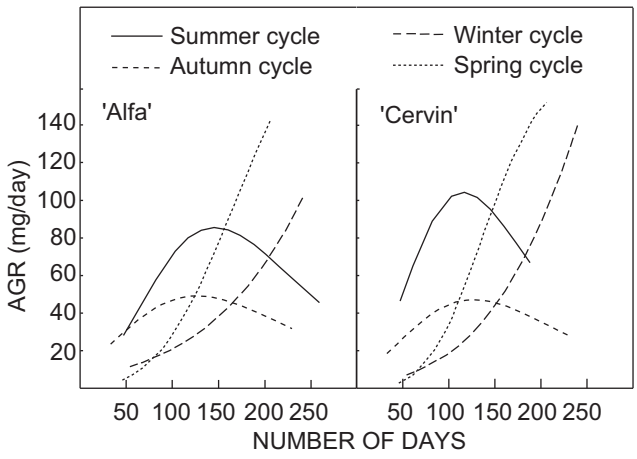

Figure 3: Absolute growth rate (AGR) (mg day^{-1}) of *Spathiphyllum* 'Alfa' and 'Cervin' during the four culture cycles (n = 12)

initiation is also reflected in the data on leaf area, plant height and total dry weight.

For each culture cycle, the daily dry weight increase of leaf blades or the absolute growth rate (AGR) of 'Alfa' and 'Cervin' is presented in Figure 3. The AGR curves of both cultivars showed important similarities. In the summer and autumn culture cycles, AGR reached a maximum and declined afterwards. In the winter and spring cycles, AGR's started at a lower level, but increased more steeply and continuously during the growing period.

Flower initiation in relation to temperature and irradiation

Date and photoperiod at the start of flower initiation, as well as the number of days, temperature and irradiation data during the pre-initiation period are presented in Table 2. Graphical presentation of percentage shoots with flower initiation per plant for *Spathiphyllum* 'Alfa' and 'Cervin' are given respectively in Figures 4a and 4b.

In the winter and spring culture cycles, 'Alfa' needed less than 100 days to start flower initiation while for the summer and autumn cycles the first flower primordia were detected after ±130 days (Table 2, Figure 4a). For the summer cycle, however, increasing formation of flower primordia was delayed till day 215 (Figure 4a). When comparing the four initiation graphs of 'Alfa' (Figure 4a) to the irradiation and temperature data of the respective culture cycles (Figure 1), a negative effect of high temperature and/or high light levels on flower initiation was observed. In winter and spring culture cycles, initiation started at relatively low light intensities and standard temperatures. For the summer and autumn cycles, flower initiation was postponed until daily irradiation suddenly dropped (from 25–20MJ m^{-2} day^{-1} to about 5MJ m^{-2} day^{-1}) and ambient temperatures declined to 22–20°C (Figure 1). Table 2 also illustrates that temperature and irradiation is associated with the number of days prior to flower initiation; lower temperature and irradiation levels during the pre-initiation period accelerated flower initiation of 'Alfa'. The cumulative irradiation sum during 'Alfa's' pre-initiation period of the winter and spring cycles was only 15% and 8% of the value of the summer culture cycle. Irrespective of the culture

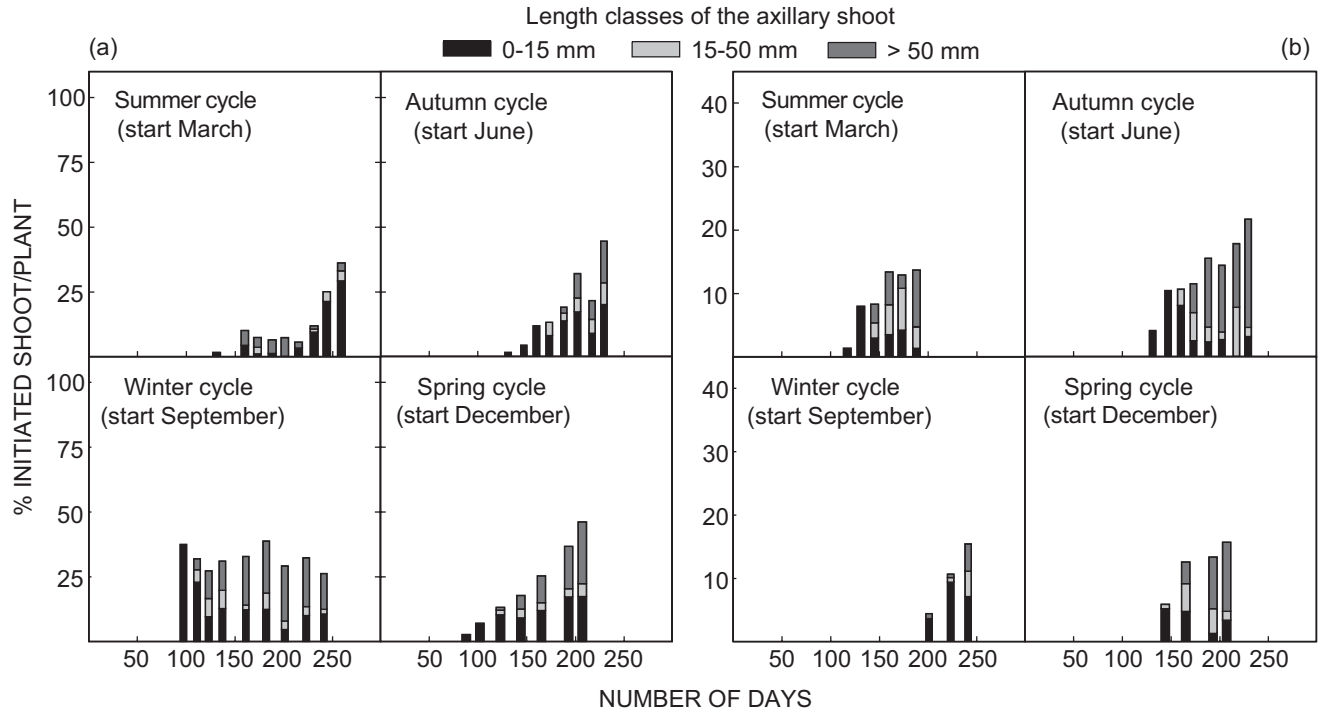

Figure 4: Percentage shoots with flower initiation per *Spathiphyllum* plant during the four culture cycles, presented as length classes of the axillary shoot (n = 12). (a) *Spathiphyllum* 'Alfa', (b) *Spathiphyllum* 'Cervin'

Table 2: Start of flower initiation and photoperiod at start of flower initiation for the four culture cycles. Pre-initiation period in number of days and total temperature sum (°C day^{-1}), mean temperature (°C), irradiation sum (MJ m^{-2}) and mean daily irradiation sum (MJ m^{-2} day^{-1}) during the pre-initation period

Culture cycle	Start of flower initiation	Photoperiod at flower initation	Pre-initation period Number of days	Temperature sum (°C day^{-1})	Mean temperature (°C)	Irradiation sum (MJ m^{-2})	Mean daily irradiation sum (MJ m^{-2} day^{-1})
'Alfa'							
Summer	(26 July)^z 19 October	(15h37)^z 10h30	(131)^z 215	(3 056)^z 5 008	23.3	(1 762)^z 2 610	(13.4)^z 12.1
Autumn	19 October	10h34	131	3 055	23.3	1 563	11.9
Winter	15 December	07h59	97	2 065	21.3	383	3.9
Spring	22 February	10h30	88	1 816	20.6	221	2.5
'Cervin'							
Summer	13 July	16h08	117	2 712	23.2	1 535	13.1
Autumn	19 October	10h30	131	3 055	23.3	1 563	11.9
Winter	30 March	12h49	201	4 236	21.1	794	3.9
Spring	19 April	14h04	144	3 013	20.9	630	4.3

^{z} early start of flower initiation

season, flower initiation of 'Alfa' started when photoperiod was reduced to at least 10h30. In the summer culture cycle, early initiation occurred under long day conditions, while the definite start was postponed until photoperiod became short (Table 2).

For 'Cervin', summer and autumn culture cycles had the lowest number of days before flower initiation (117 days and 131 days respectively) while the winter and spring cycles required longer periods to reach this stage (201 days and 144 days respectively) (Table 2, Figure 4b). The flower initiation graphs of 'Cervin' (Figure 4b) did not match the irradiation and temperature graphs as well as those for 'Alfa'. In contrast to 'Alfa', flower initiation of 'Cervin' was not delayed in the summer cycle; initiation started and continued in July (Table 2, Figure 4b) when temperature and irradiation levels were still elevated (Figure 1). For 'Cervin', the low irradiation sums and temperatures during the pre-initiation period of the winter and spring cycles corresponded to the highest number of days prior to flower initiation (Table 2). Whereas 'Cervin's' summer and autumn cycles had the lowest number of days prior to flower initiation but the highest average temperature and cumulative irradiation sums (approximately twice the amount of the winter and spring cycles) during the pre-initiation period. Photoperiod at the start of flower initiation of 'Cervin' was at least 10h30 (Table 2).

Discussion

The results clearly indicated that flower initiation of 'Alfa' and 'Cervin' is driven by different mechanisms. For *Spathiphyllum* 'Alfa', daily irradiation and temperature prior to initiation increased from spring through winter to autumn and summer cycles, resulting in an equivalent increase of the pre-initiation period. For every culture cycle, the start of flower initiation of 'Alfa' was accompanied by either decreasing or low light intensities, non-elevated temperatures and shortening of the photoperiod. In the winter and spring cycles, initiation was accelerated by about 40–120 days in comparison to the autumn and summer cultured plants (Table 2).

The delay of flower initiation in the summer and autumn cycles could, partly, be attributed to the extreme high temperatures during this period of the year; average temperature a day often exceeded 25°C. It is well known that supra-optimal temperatures (higher than 26°C) in summer can delay flower initiation in *Spathiphyllum* (Henny 1986, Verberkt 1993). In *Phalaenopsis*, flower development can also be blocked under high temperatures (30/25°C day/night); this can be prevented by GA_3 treatment (Chen *et al.* 1994). Results of Su *et al.* (2001) imply that the high temperature inhibitory effect on flowering of *Phalaenopsis* is mediated through its effect on lowering the level of endogenously active GA's.

High light intensities can also inhibit flowering of *Spathiphyllum*. Hendriks (1992) recorded a doubling of the number of flowering plants when light intensities in summer were reduced to 30% of natural light intensity. Yet, in our experiment, flower initiation was accelerated when cumulative irradiation sum in the pre-initiation period was reduced to 8–15% of the summer cycle. Since high light intensities in summer favour photosynthesis, effects of light intensity on flower initiation can also be linked to vegetative development. In *Spathiphyllum* 'Alfa', a certain competition between vegetative and generative development was observed. For summer and autumn cycles, plants seemed to invest in vegetative growth, stimulated by higher light levels. In these culture cycles, initiation started when the absolute growth rate had passed its maximum. For the winter and spring cycles, initiation started when growth rates were low (Figure 3). Competition between vegetative and generative development was reported by Lang (1965). In temperate grasses which are SLD plants, the degree of primary induction is negatively correlated with plant height (leaf sheath and blade length). Retardation of vegetative growth is most likely related to this initial step in flower induction (Heide *et al.* 1998).

In addition to decreased light and temperature levels, a reduced photoperiod is another possible condition promoting flower initiation. Although *Spathiphyllum* is categorised as a day neutral plant (Henny 1986), our results indicate that

a facultative effect of shortening of the photoperiod on flower initiation can not be excluded.

For *Spathiphyllum* 'Cervin', however, no linkage of climatic conditions and the start of flowering was observed. High summer temperatures did not postpone initiation of 'Cervin'. These results for 'Cervin' are in agreement with those for *Zantedeschia*, also a member of the Araceae, where no environmental control of floral initiation was found (Corr and Widmer 1990). Flower initiation of 'Cervin' required a minimal biomass of approximately seven shoots and 24 leaves (Table 1). In winter and spring cycles, initiation started when light intensity and temperature started to increase (Figure 1), and when AGR reached a level comparable to the level of the summer cultured plants at initiation (Figure 3). This suggests that flower initiation of 'Cervin' required a larger pool of carbohydrates. The role of daily light (photoperiod) and temperature sums seemed more of a supportive nature, than acting as a trigger for initiation.

A *Spathiphyllum* plant should have a minimal vegetative biomass before generative development is started in order to obtain a plant of commercial quality. In spring culture cycle, flower initiation occurred very early, consequently only a single-shoot stage with as few as seven leaves was achieved. Temperature, irradiation and photoperiod are closely related to each other in any experiment; therefore, the role of these individual factors in flower initiation of *Spathiphyllum* should be investigated in further research.

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